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(54) Title: METHOD AND APPARATUS FOR DETECTING THE PRESENCE OF FLAME IN THE EXHAUST PATH OF A GAS TURBINE ENGINE

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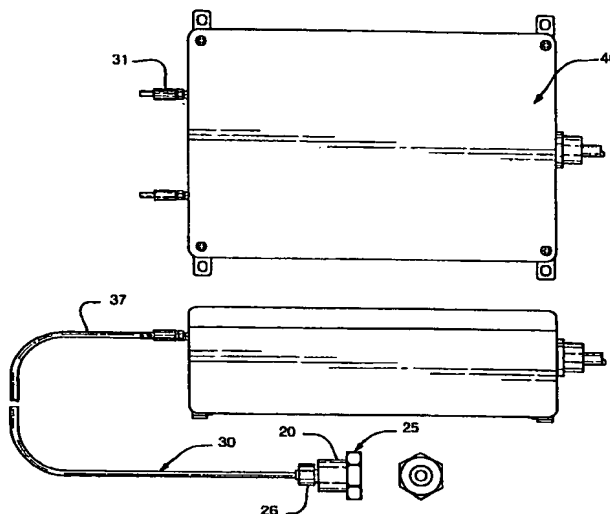
(57) Abstract: A method and apparatus for monitoring the exhaust path of a gas turbine engine for the presence of unwanted flames downstream from the main combustion chamber(s). The system is comprised of an Electro-Optics Module containing sensors and associated processing electronics as well as collection and transmitting optics, which relay the radiant energy generated by a flame event to the sensors. The information generated by the sensors is directly related to the time based intensity of the flame event, which can suggest problems associated with the condition of combustion related engine components. This information can then be used by the engine owner/operator to assess the condition of the engine and determine the more efficient required maintenance schedule.

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METHOD AND APPARATUS FOR DETECTING THE PRESENCE OF FLAME IN THE EXHAUST PATH OF A GAS TURBINE ENGINE

5   CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/388,604, filed June 3, 2002, the contents of which are incorporated in their entirety.

10

FIELD OF THE INVENTION

This invention relates to flame detection, and especially to a solid state, fiber optic linked flame sensor that is particularly useful in connection with sensing the flame in a gas turbine exhaust path as a means of determining the condition

15   of the fuel nozzle(s).

BACKGROUND OF THE INVENTION

The life cycle cost reduction for capital equipment such as gas turbines is of great importance to end users such as the Navy, the shipping industries and

20   power generation stations to name a few. Regular maintenance of gas turbine equipment by the operators is necessary to maximize performance and fuel efficiency however the associated increased maintenance costs offset the benefits of shorter maintenance intervals. Achieving the optimal maintenance plan, which minimizes the total operation and maintenance costs, depends on the

25   availability of accurate performance degradation assessments from diagnostic and prognostic technologies.

These maintenance-timing decisions were historically founded on rigid schedules based upon hours of use or when the operator noticed a severe degradation in the performance or efficiency of the turbine. The maintenance-timing was determined from examining the various turbine components during

5   normally scheduled maintenance or through mechanical failure and estimating whether the average turbine should be maintained in a shorter or longer interval to maximize efficiency and minimize maintenance costs. The shortfall of this method was that the maintenance schedule was based on the average condition of a fleet of given turbine types, where unnecessary maintenance was done on

10   some turbines where needed maintenance was forgone on other turbines resulting in poor performance or worse, catastrophic failure and overall added costs. In some turbines, when an injector or injectors were sufficiently clogged, the combustion process is uncontrolled and can cause visible flash of flame in the exhaust. This is hard to determine without specific diagnostic equipment that has

15   been historically a thermocouple. The problem is that once the degradation was significant enough for the operator to perform out of schedule maintenance excessive fuel was wasted or worse was that fouling of the fuel nozzle caused harm to the turbine because of the shortfalls of the prior art diagnostic equipment.

Specifically, fuel nozzle fouling, can cause "hot starts" where uncontrollable

20   ignition results in flame propagation through the turbine and damage to hot section components which necessitates expensive repairs and removing the affected turbine from service.

The Allison 501 turbine engine is used frequently in the Navy for shipboard power generation. The fuel nozzles in the Allison 501 engine often become clogged with internal or external carbon deposits. Fouling typically affects the pilot injection port more severely than the main port. The pilot port is used during engine

5 startup and idle when the fuel flow rate is too low for proper atomization by the main port. A pressure-driven flow divider directs the flow to the appropriate port for proper atomization of the fuel for operation.

The fuel spray pattern is adversely affected by clogging and can lead to flame position problems that burn hot section components, and increases

10 potentially damaging "hot starts" or "no starts". Clogged injectors can delay ignition ('light-off') during engine start-up and cause a buildup of fuel in the combustor. When ignition finally occurs, the unusually rich fuel/air mixture can cause excessive gas temperatures, temperature gradients and pressure gradients that damage hot section components. The excess fuel often produces a flash of

15 flame in the engine's exhaust as well that may be detected visually.

DESCRIPTION OF THE KNOWN PRIOR ART

Earlier flame detection systems which have been used to monitor various gas turbine combustion processes include thermocouples, gaseous discharge

20 ultraviolet detectors, and, more recently, silicon carbide (SiC) ultraviolet detectors. Thermocouples have been used in the combustion chamber area as well as in the exhaust gas stream. The problem of the thermocouple prior art in addition to

having too slow of a response time to adequately sense flame, thermocouples do not last for long periods in the highly oxidizing atmosphere of a gas turbine.

Gaseous Discharge UV detectors have traditionally been used to validate the proper ignition of the combustion flame. They are extremely fast devices with

5 a wide operating temperature range. When properly constructed they are non-responsive to the radiant energy of hot surfaces in the combustion chamber. Their drawbacks are in many ways related only to industry perception. More specifically, they are considered by most to be antiquated technology. Additionally they suffer from requiring supply voltages in excess of 325 volts DC.

10 Silicon carbide UV sensors are considered by most to be the modern replacement for the Gaseous Discharge UV detectors.

Turbine manufacturers and users are not presently known to be making use of any optical means to alert them to the presence of a flame in the exhaust section of their engines. Rather, they are utilizing thermocouple arrays to profile

15 the temperatures in various locations throughout the exhaust path stream. The time durations of the flame events observed during our testing were so short (in the realm of a second or less), that thermocouple technology would not be responsive enough to accurately detect them. Therefore the improvement in reducing unnecessary maintenance costs is minimal and not cost effective using

20 a thermocouple because of the shortfalls consistent with that method of monitoring flame in the exhaust section of the turbine.

OBJECTS OF THE INVENTION

Accordingly, it is an object of the instant invention to provide a method of determining the condition of the nozzle fouling to maximize fuel efficiency.

It is an object of the present invention to detect the presence of a flame, as

5   it exists in the exhaust path of a gas turbine engine.

It is a further objective to be able to delineate differences in the intensity and duration of flame presence in the exhaust stream of a gas turbine engine.

It is yet another objective to be able to assign a measure of nozzle fouling (coking) certainty as a result of the analysis of the signal generated by the

10   electronics of the optical monitoring equipment.

It is a continued object of this invention to serve in a feed back role to a centralized control system acting in the capacity of a Conditioned Based Monitor, for equipment operation maintenance.

15   SUMMARY OF THE INVENTION

The present invention achieves the above-described objectives by providing an Electro-Optics Module (EOM), Fiber Optic Cable Assembly and an Optical Viewing Port or alternatively a sensor directly mounted that produces a signal in the presence of a flame directly attached to the exhaust port. The EOM houses

20   the sensor(s) and signal processing electronics. The Optical View Port mounts to the gas turbine engine preferably down stream from the combustion chamber(s) and collects the radiant energy from the flame and focuses it on the tip of the Fiber Optic Cable Assembly. The Fiber Optic Cable Assembly transmits the

radiant energy collected by the Optical View Port to the sensor(s) located inside the EOM.

The sensor(s) may optionally be assembled in modules containing optional custom discrete optical filters and amplification circuitry. The optical filters

5   guarantee that the spectral energy reaching the sensor elements is restricted to wavelengths specific to the signatures of the flame source, however any sensors respondent to unfiltered energy within the visible light spectrum would satisfy the inventions requirements.

The sensor analog signals, which are proportional to the intensity of the

10   radiant energy received, are optionally recorded either on a physical chart or indicator, or preferably converted to digital signals and fed into the EOM's microprocessor where they are compared using the Meggitt developed algorithms. The result of the processed signal is a determination of flame signal intensity and its duration. These time and date stamped signal traits are stored

15   within the EOM's self-contained memory for later evaluation. Additionally these signals are available to be fed to the Condition Based Monitoring data collection center for the engine.

BRIEF DESCRIPTION OF THE DRAWING

20   FIG. 1 is a plan view of a fiber optic linked flame sensor.

FIG. 2 is a partial side view of an optical probe.

FIG. 3 is a partial cut-away view of a fiber optic cable.

FIG. 4 is a partial cut away view of an individual fiber.

FIG. 5 is a view in a schematic form of an electro-optics module.

FIG. 6 is a theoretical plot of the relative spectral signature of a burning hydrocarbon fuel together with specific emission bands and various sensor detection regions.

5   FIG. 7 is a plot of the typical spectral response of an OSRAM BPW 21 Silicon Photodiode.

FIG. 8 is a plot showing the spectral irradiance differences between a bench-top propane Bunsen burner source and a 1900°K graybody in the ultraviolet region.

FIG 9 is a pictorial representation of a flash event analysis as performed by 10   the detection algorithm.

FIG. 10 is a table with test fuel nozzles and their known performance characteristics.

FIG. 11 is a table showing resulting flame presence in the exhaust section of a gas turbine in relation to the condition of the fuel nozzle.

15   FIG. 12 is a reading (raw signal) of spectral energy observed in the exhaust section of a gas turbine with a clogged nozzle.

DETAILED DESCRIPTION

In reference to FIGS. 1-5, according to one potential embodiment of the 20   present invention is at least one fiber optic flame sensor 10 for monitoring the presence and/or intensity of the flame in the exhaust section of a gas turbine engine generally consists of three component sections; a high temperature probe or optical viewing port 20, at least one fiber optic cable 30, and an Electro-Optics

Module **40** (E.O.M.). As described in detail below, the high temperature

probe/optical viewing port **20**, mounts directly on the engine in a location, which

will provide an adequate view into the exhaust portion of the turbine thus acting

as a sight pipe. The fiber optic cable **30** transfers the radiant electromagnetic

5 energy emitted by an uncontrolled combustion flame from the viewing port **20** to

the E.O.M. **40**. The E.O.M. **40** preferably contains solid-state electronics for

converting a selected wavelength region of the radiant electromagnetic energy to

an electrical signal that is monitored, in a known manner, to determine the

presence or absence of the undesirable flame in the exhaust plenum. The

10 electrical signal thus indicates the presence of a flame, or absence of flame

depending on the setup of the equipment. Furthermore, the monitoring can

include the gathering of additional information about the flame condition such as

intensity and duration of the event. In FIG. 8 it displays the difference between a

bench-top propane Bunsen burner flame **56** and a 1900°K greybody **58**. The

15 difference is clearly discernable to an accurate sensor calibrated to a flame

radiation source.

The E.O.M. **40** could optionally use an analog method such as a simple

visual indicator such as an indicator light or a paper chart that would serve as a

record of the event of flash in the exhaust that has a very short duration. Or the

20 signal can be converted to a digital signal for further processing by a digital

computer. An example of an optical view port and fiber optic linked cable

assembly suitable for use are further described in U.S. Patent 5,828,797 entitled

"Fiber Optic Linked Flame Sensor", the contents of which are herein incorporated

by reference in their entirety. Several concepts related to the monitoring of a

flame are disclosed in U.S. Patent No. 6,071,114 entitled "Method and Apparatus

For Characterizing a Combustion Flame", which is also incorporated by reference

in its entirety.

5   Turning now to FIG. 2, the optical viewing port **20** is constructed of high

temperature materials that can withstand the intense temperatures associated

with the exhaust gasses. Preferably, the end portion **25** of the port **20**, which

mounts to the exhaust section may be constructed of either 316L stainless steel

or Hastelloy X due to its corrosion resistant nature at elevated temperatures and

10   in marine environments. The end portion **25** of port **20** mounts to the exhaust of

the turbine preferably using threads **27**, that are ¾ NPT mounting threads.

Threads **27** can be replaced with welding, riveting, quick disconnect or various

other methods of fastening known in the art. It is preferable that the fitting be

standardized and provide a good seal to avoid escape of turbine exhaust gasses.

15   A thread fit is therefore preferable because it is inexpensive and effective at tightly

connecting and sealing the probe to the exhaust while allowing for ease of

removal.

Additionally, other materials with similar minimum performance

characteristics can be utilized in other possible probe configurations and material

20   combinations to provide the needed site pipe into the exhaust chamber of

probe/port **20**.

In particular, it is important that whatever material is used in the

construction of the optical view port probe, it must not impart undue strain to the

Kovar ring **29** containing the brazed sapphire window **28**.   The port **20** acts as a

sight pipe into the exhaust section and may contain a braze-sealed sapphire lens

28. The instant invention only requires that the port **20** act as a minimum as a

sight pipe and therefore it is anticipated that many substitutes may be fashioned

5   as long as it has the capacity to withstand the heat of the turbine exhaust and

simultaneously transmit the spectral radiation from the flame in the exhaust path

to the E.O.M. **40**, or it can be replaced with a sensor assembly capable of directly

monitoring the presence of flame. The end portion **25** of port **20** mounts to the

gas turbine's exterior exhaust housing, preferably positioned as close to the

10   beginning of the exhaust section as feasible ensuring that the Radiant energy is

transferred from any flame present in the exhaust into the sight tube bore **24** of

the probe **20** through opening **23**, and then to the fiber optic cable interface **26**

into the fiber optic cable **30**. The Radiant energy is potentially, but not limited to

all light/energy produced within the spectral range of 200 nm to 800 nm, but

15   preferably it is the frequency associated with the presence of a flame; this would

obviously include all the electromagnetic frequencies in the infrared associated

with the by products of hydrocarbon combustion such as H_2O and CO_2.

In one embodiment, the probe **20** has an overall length of about 2.2 ∀, and

the sight tube opening **24** containing ¾ - 14 NPT threads and a lens aperture of

20   approximately 0.48 ∀, these dimensions are not critical and can be changed

based on matching the physical parameters of the least expensive components

produced at the time of manufacture and the physical requirements as they relate

to efficient access to the exhaust stream.

●
●

The probe **20** dimensions are not critical as long as it functions to efficiently couple the radiant energy from exhaust of the gas turbine to the optical cable **30**. The optical cable **30** can potentially be eliminated if the E.O.M. **40** is sufficiently dimensioned to fit directly upon probe **20** and heat resistant enough to survive

5 close proximity to the exhaust environment of the gas turbine or a flame sensor **10** (direct mounting of the flame sensor to exhaust not displayed) is of sufficient construction and cost effective to be directly mounted to the exhaust portion of the turbine.

The sapphire lens **28** is braze-sealed to a Kovar ring **29**, which then is then

10 welded **21** into the probe body **20**. The sapphire lens seal is preferred because it is capable of withstanding gas temperatures of 900 degree F at pressures reaching 500 psi, but other materials can be substituted having suitable characteristics for the monitoring environment. This lens **28**, therefore, acts as the protective barrier separating the combustion process from the other optical

15 system components. The sapphire lens **28**, Plano convex in the preferred configuration, focuses the radiant emission energy resultant from the combustion process into the suitable acceptance angle matching the numerical aperture of the fiber optic cable **30**, the tip of which is inserted into cable interface **26**. The interior walls of Kovar ring **29** of the brazed lens assembly welded within the sight

20 probe are optionally plated with gold or other suitable materials to help prevent oxidative contaminants from fouling the optical surfaces.

● ●

The fiber optic cable **30** transfers the radiant energy projected through the high temperature probe lens **28**, from the errant flame potentially present in the exhaust stream to the (E.O.M.) Electro-Optics Module **40**.

Referring to FIG. 3, the fiber optic cable **30** contains at least one optical

5   fiber **33** and may be composed of a plurality of individual fused silica optical fibers **33**, and is preferably as short as possible in length to minimize losses but distances of about twenty feet or more in length are possible. Other materials that provide the necessary light transmissibility such as polymers may be substituted if they are capable of long-term use in the environment of the turbine.

10   As shown in FIG. 4, in one embodiment an optical fiber **33** has a core **34** that has a low transmission loss, typically used is a pure fused silica that is preferably 200 micrometers (microns) in diameter or other materials such as polymers that offer sufficient transmission of energy over the desired cable length.

Optionally, if required for sufficient energy transmission for longer selected

15   cables, over the core **34** is a cladding **35** composed of doped fused silica 10 microns thick. A buffer layer **36** of either polyimide or gold covers the cladding **35** in a thickness of about 5-15 microns, preferably 10 microns. In the first few inches, preferably about six to twelve inches, of the fiber optic cable at the high temperature probe end **37** (FIG. 1) of the cable; a gold buffer layer **36** rated at

20   900 degree F is used. The remainder of the cable is provided with a polyimide buffer **36**, rated at 540 degree F.

A more cost effective cable construction can be designed that eliminates some or all of the above described features. The cable is limited in its design only

in that it must provide sufficient transmission of radiant energy to the sensor(s) and capable of withstanding the environment in which it is routed either in a high or preferably that of low heat environment to reduce expenses. It would be an obvious modification to one skilled in the art to design more or less features into

5 the cable to save expense or to design for a less heat intensive environment.

As shown in FIG. 3, one potential configuration of the group of a plurality of fibers **33** is closely packed in a hexagonal arrangement and sheathed in fiber glass cloth **38** and a stainless steel braid **39**. The ends of the cable **37** that are terminated in stainless steel ferrules **31** (FIG. 1) of a proper shape and size to

10 interface with the high temperature probe **20** on one end, and the E.O.M. **40** on the other end. The minimum amount of fibers needed to transfer the radiant energy to the sensor is one, but additional fibers may be added for use with additional sensors or for redundancy purposes.

Turning to FIG. 5, the Electro Optics Module **40** (E.O.M.) is preferably

15 located at the so-called low temperature end of the fiber optic cable **37**. The ambient temperature where the E.O.M. is located is preferably no greater than 125 degree C., thus permitting conventional, low cost electronics to be used in the E.O.M. **40**. The function of the E.O.M. **40** is to convert the radiant energy transmitted from a flame through the fiber optic cable **30** into an electrical output

20 signal. To accomplish this, the tip **41** of the low temperature end **37** of the fiber optic cable **30** directs electromagnetic radiation with the aid of focusing optics **43** onto the active area of a solid state sensor **44** mounted optionally on a circuit board **45**. Input and output to the circuit board is provided through a port **46** on

the E.O.M. 40. The port 46 is preferably connected to a recordation device 48.

On the occurrence of a flame-condition in the exhaust path, the radiant energy at

the sensor 44 causes the E.O.M. 40 to provide an electrical signal, in a known

manner, to the memory storage apparatus 48, either digital or analog indicating

5   potential nozzle fouling to the operator or control electronics of the turbine.

One potential choice for solid-state sensor 44 is a Silicon Photodiode that

is sensitive to the presence of a flame, which is usually filtered to monitor only the

spectral range of a flame. This detector (BPW 21) is produced by OSRAM Opto

Semiconductors that are available in TO-5 transistor cans. Other types of

10   sensors may be substituted provided that they respond to at least a portion of the

radiant energy produced from the flame in the wavelength range of 200 nm to 900

nm. The sensor 44 may be part of an optional transimpedance amplifier circuit 47

that generates a voltage output signal proportional to the intensity level of the

radiation received within a specific spectral bandwidth.   In addition to containing

15   the sensor 44 and amplification electronics 47, the E.O.M. also may optionally

contain processing electronics 49, depending on a user's requirements.

In FIG. 6 a chart displays a spectrum of 200 to 750 nm and the relative

spectral signature of a burning hydrocarbon and various sensor detection regions.

Alternative detectors that can be selected are constructed using wavelength

20   selecting sensing elements such as SiC (200 – 375 nm), GaN (200 – 365 nm),

AlGaN (200 – 320 nm), and a relatively new UV photodiode having a spectral

response range from 215 to 387 nm. This UV photodiode is based on

semiconductor technology whereby a thin film deposition via the sol-gel process

on the semiconductor determines its spectral properties. All of these detector

types are available through Boston Electronics Corporation, Brookline MA.

Although hydrocarbon flames are know to have a significant emission peak

at 310 nm, the data acquired during testing would seem to indicate that there may

5   not be enough radiant energy present in the exhaust path flame to excite these

types of detectors without additional components to increase signal intensity. It is

not to say that if mounted in a different location on the engine, however, that they

would not work sufficiently well.

In an alternative method using these types of detectors, the selective

10   spectral response could be considered advantageous. This would be the case in

an application where the exhaust plenum may have many openings where

ambient visible light may result in a false flame event. These events could occur

if the viewing probe were to collect the energy produced by reflected sunlight or

high intensity inspection lighting equipment. During the testing associated with

15   this instant invention, there were no adverse effects realized with the ambient

lighting present in the turbine package. More specifics as they relate to flame

sensing with detectors such as those similar in nature to SiC UV detectors can be

found in U.S. Patent No. 5,828,797 and is incorporated in its entirety.

Alternative detectors having a spectral response from 200 nanometers

20   (nm) to approximately 375 nm include, Gallium Nitride (GaN) UV detector

available from APA Optics, Inc., Minneapolis, Minn., and Silicon-on-Insulator

technology based UV photodiodes available from Spire Corporation, Bedford,

Mass.

In one embodiment the sensor **44** is a SiC UV photodiode detector that has a UV spectral response that is suitable for detecting the presence of a flame in the exhaust path. Referring to FIG. 6, a dramatic spike **50** is shown in a plot of the radiant emission energy from a burning hydrocarbon fuel the spectral radiant

5   intensity of the emission is centered at 310 nm.   FIG. 7 displays, the spectral response **51** for a BPW21 Silicon Photodiode useful for detecting the emission of the flame of a burning hydrocarbon with its most effective range being about 300 to 800 nm.

     Currently only a few different types of sensors are utilized to monitor the

10 energy output of flame mostly because of cost associated with choosing other less common sensors. This list represents a few of possible wavelengths that one may possibly wish to monitor to determine the presence of flames as alternatives to the current sensors currently utilized.

Flame Species wavelength (nm)	Element Center Wavelength (nm)	Emission Species (compound or molecule)	Relative Emission Strength 1 to 7	Element I. D.	Relative Electronic Emission Strength	Comments about emissions
	234.8			Be	950	
	234.9			As	350	
	249.7			B	1000	
	255			P	950	
	265.9			Pt	2000	
	282			Hf	1200	
	287.8			Sb	1000	
	288.2			Si	1000	
	303.9			Ge	750	
306.4		OH-	6			
	306.8			Bi	9000	
312.2		OH-	6			
314.4		CH	7			
315.66		CH	6			
318.5		OH-	2			

	322.1			Ir	5100
325.4		OH-	1		
	326.5			Cu	10000
	331.1			Ta	1100
336		NH	2		
358.4		CN	3		
358.6		CN	3		
358.7		C2	3		
359		CN	2		
	379.8			Mo	29000
386.2		CN	1		
387.1		CN	6		
388.3		CN	6		
387.2		CH	6		
	396.1			Al	9000
	403.3			Mn	27000
	405.8			Pb	95000
	407.9			Nb	12000
	413.8			Ce	2700
	417.2			Ga	10
	422.7			Ca	50
	426.5			Cr	20000
	426.7			C	1000
431.2		CH	7		
	432			W	2200
432.4		CH	7		
	435.8			Hg	4000
	(253.6)				(15000)
436.5		C2	7		
437.1		C2	7		
	437.9			V	12000
438.3		C2	7		
	439.7			Fe	3000
	442 (352.4)			Ni	110 (8200)
	451.1			In	18000
	452.5			Sn	40
	455.4			Ba	65000
	458 (460.3)			Cs	100000
466.9		C2	7		
	467			Sr	65000
467.9		C2	7		
468.5		C2	7		
469.8		C2	7		
471.5		C2	7		
473.7		C2	7		
477		C2	2		
	477.2			Zr	870
	481.4 (345)			Co	100
					(21000)
	498.7			Ti	5800
499.7		C2	7		
509.8		C2	7		

Original Wavelength	Band Head Center	Species	Number	Element	Value
512.9		C2	7		
516.5		C2	7		
	518 (285.2)			Mg	400 (6000)
	535			Tl	18000
	546 (328)			Ag	1000 (55000)
547		C2	5		
550.2		C2	6		
554.1		C2	6		
558.6		C2	6		
563.6		C2	6		
	589.5			Na	80000
590		C2	2		
592.3		C2	2		
595.9		C2	5		
600.49		C2	5		
605.9		C2	5		
612.2		C2	5		
619.1		C2	5		
	627.8			Au	600
	636.2			Zn	1000
	643.9			Cd	2000
653.4		C2	1		
659.9		C2	2		
667.7		C2	2		
676.3		C2	2		
	678 (671)			Li	3600
685.9		C2	2		
722.7		H2O	6		
746		OH-	6		
	766.5			K	25
771.5		C2	6		
	780			Rb	90000
785		OH-	6		
790.8		C2	6		
795.7		H2O	6		
810.8		C2	6		
822.7		H2O	6		
827.8		OH-	6		
875.1		C2	6		
898.1		C2	6		

Infrared

Original Wavelength (microns)	Band Head Center

1.8752		H2O	v. strong	
2.3467	2.2929	CO	"	vib-rotation overtone
3.3762	2.3221	CO	"	
2.4064	2.3519	CO	"	
2.6618		H2O	v. strong	
2.6912		CO2	strong	
2.7337		H2O	strong	
2.7672		CO2	strong	
2.8007		OH-	weak	masked by CO2 and H2O
3.1722		H2O	strong	
4.2557	4.1713	CO2	v. strong	modified by self absorption
4.279	1.1912	CO2		
4.2955	4.211	CO2		
4.297	4.2057	CO2		
4.3014	4.214	CO2		
4.6644		CO	moderate	self absorabed and
4.7228		CO	"	masked by
4.7825		CO	"	CO2
6.2698		H2O	v. strong	
13.8699		CO2	moderate	intensity about 1/200th of
14.9794		CO2	"	4.3 micron intensity

There is thus provided a fiber optic linked flame sensor which provides rapid, reliable, and cost effective optical monitoring of the presence of flame within the exhaust chamber of a gas turbine engine to provide reduced

5   maintenance costs through the accurate diagnosis of the presence of a clogged fuel nozzle without teardown of the turbine.

As discussed previously the spectral energy indicating the presence of flame in the exhaust of a turbine can encompass the entire visible spectrum and wavelengths of 200 to 1000 nm. The wavelength monitored with sensors can

ideally range from 200 nanometers (nm) to 800 nm. The CH emission band head

at 431 nm, monitoring from 350 to 500 nm, and the OH emission band head at

310 nm monitoring from 250 nm to 400 nm have been found to be effective in

practice. Additional spectral data from the current broadband region of about 550

5   nm to 650 nm, and the broadband region of 400 nm to 500 nm are also effective

in flame detection given the absence of background radiation sources with

sufficient energy to excite these sensors.

Further sensor detection of flame can be accomplished in the infrared

regions. The regions of 2.9 and 4.4 micrometers that have been associated with

10   flame detection and therefore sensors capable of fast response time in the region

of approximately 1.0 to 5.0 micrometers can also satisfy the flame detection

requirements. The sensor utilized should be capable of responding in less than

approximately 100 microseconds (μs), but may still be effective between 100 and

300 microseconds to effectively monitor the presence of flame in the exhaust

15   depending on its duration within the spectrum discussed above. A detection

system based solely on infrared technology would require fiber optic core

materials other than fused silica. One option would be to use sapphire, however

at this time this option would be extremely expensive and a less cost effective

solution.

20   In another embodiment remote monitoring of the flame event using a fast

scanning miniature spectrometer is performed. This embodiment uses fiber

optics to locate the spectrometer to an environment, which is conducive to its

operating limits. The basic principle of operation would be as follows: Light

gathered by the view port attached to the exhaust plenum and transmitted by the

fiber optic cable enters the spectrometer through a fixed aperture. The light

energy then strikes a collimating mirror and is directed at the diffraction grating.

The light is refracted by the grating and directed toward a focusing mirror. The

5   diffracted light strikes the focusing mirror where it is reflected and focused onto a

detector array. In front of the detector array is a lens, which concentrates light

onto the individual detectors. There is also an order sorting filter known in the art

to limit the effect of second and third order wavelength harmonics. Finally, each

detector element (pixel) responds to the individual wavelength of light that strikes

10   it. The signals are then fed into a microprocessor, which interprets the various

signal strengths and produces information relative to the intensity of the individual

wavelengths of light as received by the detector array. This information can then

be used to determine the spectral nature of the flame condition being monitored.

This sensor technology as produced by Ocean Optics Inc., Dunedin, FL.

15   This can be configured and customized to meet the needs of the

application, i.e., usable spectral range. The total spectral capability of such a

system can be realized from 200 nm up to 1600 nm. However, to scan the entire

range would require more than one spectrometer being supplied the same energy

from the flame. The optical signal could be split and fed to however many

20   spectrometers are required in order to accurately assess the spectral nature of

the flame.

The basic configuration of such a system as produced by StellarNet Inc,

Oldsmar, FL, is describe below. StellarNet's miniature fiber optic spectrometers,

industrial process probes, optical fibers, light source accessories and

SpectraWiz® software are process control and quality control monitor workhorses

for analytical instrumentation designed to measure light wavelength absorbance,

transmission, reflection, color, emission, irradiance, and fluorescence.

5   Measurements for ranges in the ultraviolet (UV 190-400nm), Visible color (VIS

350-850nm), short-wave Near Infrared (NIR 500-1200nm), and Near Infrared

(XNIR 1200-1600nm) are easily performed by portable EPP2000 ™ (parallel port

interface) or ISA2000 ™ (PC plug-in card) fiber optic spectrometers.

CCD or Photo Diode Array spectrograph optics have no moving parts or

10   detector sockets and could be utilized in flame detection. The units are designed

to be vibration tolerant and use thermal stabilization suitable for process

applications. The EPP2000C ™ spectrometer has no mirrors. It uses an

aberration corrected holographic, concave diffraction grating for superb imaging

while minimizing stray light. This instrument covers the UV and VIS ranges in one

15   unit (190-850nm).

There is also similar technology developed, which will provide the same

type of information from 1.0 micrometers (μm) to 5.0 μm. This equipment is

available through Spectraline Inc., West Lafayette, IN. There has already been

work done and published in the area of flame research using this type of

20   equipment. NASA Tech Briefs, published in November 2000 authored by

Yudaya Sivathanu and Rony Joseph of En'Urga Inc. for Glenn Research Center.

A spectrometer has been developed for acquiring transient emission and

absorption spectra in the wavelength range from 1.2 to 5.0 μm and could be used

to characterize flames, turbulence, and other transient phenomena that interact with infrared radiation. In one potential embodiment an infrared spectrometer measures the spectrum at a repetition frequency of 390 Hz. The spectrometer optics include a chopper, two prisms that serve as dispersers, and parabolic

5   optical-path-folding mirrors. The spectrally dispersed light is projected onto a 160-pixel linear array of lead selenide photodetectors. The spectrometer also includes electronic circuitry for controlling the chopper, synchronizing readout from the pixels with the chopping cycle, and sending data to an external computer or data logger.

10   A method of determining presence of flame or fuel nozzle condition of the present invention comprises the steps of: providing an Electro-Optics Module (EOM) **40**, Fiber Optic Cable Assembly **30** and an Optical Viewing Port **20**; monitoring the operation of the turbine with a sight pipe prior to the commencement of operation of the turbine; operating the gas turbine; transferring

15   radiant energy from the turbine exhaust section via a fiber optic cable **30**; determining with the EOM **40** that a condition of flash exists; indicating to the operator the presence of flash in the turbine exhaust.

A method of detecting the presence of flame in the exhaust further comprises the steps of providing sensor(s) and optional signal processing

20   electronics. The Optical View Port **20** mounts to the gas turbine engine and collects the radiant energy from the flame and focuses it on the tip of the Fiber Optic Cable Assembly **30**. The Fiber Optic Cable Assembly **30** transmits the

radiant energy collected by the Optical View Port to the sensor(s) located inside the EOM **40**.

The sensor(s) are assembled in modules optionally containing custom discrete optical filters and amplification circuitry. The optical filters guarantee that

5 the spectral energy reaching the sensor elements is restricted to wavelengths specific to the signatures of the flame source.

The method of detecting the presence of flame in the exhaust further comprises the steps of converting an analog signal to a digital signal; comparing signals via an algorithm; storing processed signal with a time date stamp within a

10 memory. The sensor analog signals, which are proportional to the intensity of the radiant energy received, are converted to digital signals and fed into the EOM's microprocessor where they are compared using the Meggitt developed algorithms. The result of the processed signal is a determination of flame signal intensity and its duration. These time and date stamped signal traits are stored

15 within the EOM's self-contained memory for later evaluation. Additionally these signals are available to be fed to the Condition Based Monitoring data collection center for the engine.

One embodiment uses a fiber optic linked flame sensor for continuous optical monitoring of the exhaust of a gas turbine engine. The system includes a

20 high temperature optical probe **20**, a fiber optic cable **30**, and electro-optics module **40**. The high temperature probe is mounted on the engine skin and sighted in a manner so as to view the exhaust gas for presence of flame that indicates fouling of the fuel nozzle or otherwise a condition of uncontrolled

combustion. The appropriately constructed fiber optic cable connects the high

temperature probe with the electro-optics module. The radiation transmitted via

the fiber optic cable is then received by a photodiode located in the electro-optics

module and coupled with appropriate electronics.

5

Test Results- Allison-501 turbine

The Allison-501 turbine consists of six nozzles arranged in a circular

pattern with a number assigned to the nozzle corresponds to the position on the

turbine, when viewed from the compressor end and numbered in a

10 counterclockwise fashion. The invention disclosed herein is tested on an Allison

501 turbine but it is applicable to all other known turbines and configurations.

One skilled in the art would be able to adapt this preliminary testing information to

monitor any other turbine's operating condition and nozzle condition to prevent

damage to the hot section of a turbine from clogged or dirty fuel nozzles.   In FIG

15 10 the conditions of the nozzles are examined. In FIG. 11 the severity of flash is

related to the condition of the nozzles of the turbine. In FIG. 12 the raw data of a

test run is displayed.

The table below represents data collection from a series of tests involving

one embodiment of the instant invention. The data collection was manually

20 initiated approximately 5 to 10 seconds before the gas turbine was started. All

runs that displayed flash in the exhaust were displayed in greater detail for the

portion of the period of flash.

| Date | Test Run | Nozzle Condition (Severity Ranking)* | | | | | | Evidence Of Visual Flash | Optical Sensor Detection (Yes/No) | Flash Duration (ms) |
		Nozzle 1	Nozzle 2	Nozzle 3	Nozzle 4	Nozzle 5	Nozzle 6			
12-Jun	1	Clean	Clean	Clean	Clean	Clean	Clean	No	Not Taken	n/a
	2	Clean	Clean	Clean	Clean	Clean	Clean	No	Not Taken	n/a
	3	Clean	Clean	Clean	Clean	Clean	Clean	No	Not Taken	n/a
	4	Clean	Clean	1	Clean	Clean	2	Small Flash	Not Taken	n/a
	5	Clean	Clean	1	Clean	Clean	2	No	Data Lost	n/a
	6	Clean	4	1	Clean	3	2	No	Yes	50 - 80
	7	Clean	4	1	Clean	3	2	No	No	n/a
	8	Clean	3	5	Clean	4	2	Small Flash	Yes	22
	9	Clean	3	5	Clean	4	2	Small Flash	No	n/a
	10	Clean	3	5	Clean	4	6	Large Flash	Yes	930
	11	Clean	3	5	Clean	4	6	Small Flash	Yes	330
13-Jun	1	Clean	3	5	Clean	4	6	Large Flame	Yes	800
	2	Clean	3	5	Clean	4	6	2 Flashes	Yes	470
	3	Clean	3	5	Clean	4	2	Medium Flash	Yes	40
	4A	Clean	4	1	Clean	3	2	No	Yes	33
	4B	Clean	4	1	Clean	3	2	Medium Flash	Yes	38
	5	Clean	Clean	1	Clean	Clean	2	Minimal Flash	?Yes?	30
	6	Clean	Clean	1	Clean	Clean	2	No	No	n/a

Ranking # 1 - Least severe nozzle fouling
Ranking # 6 - Most severe nozzle fouling

The table displays the information obtained from the test and the known condition of the nozzle immediately prior to the onset of testing confirmed through a visual inspection of each nozzle. The instant invention was shown to provide the time duration and relative intensity of the flash event. The data shown above shows a high correlation between the condition of the nozzle(s) and presence of flame in the exhaust and provide a strong predictive tool useful in determining a maintenance schedule for each independent gas turbine to maximize performance and eliminate unexpected downtime.
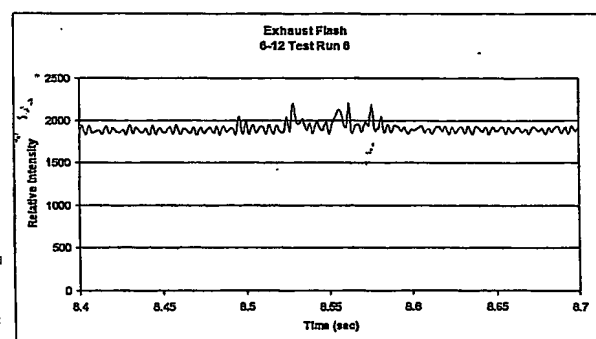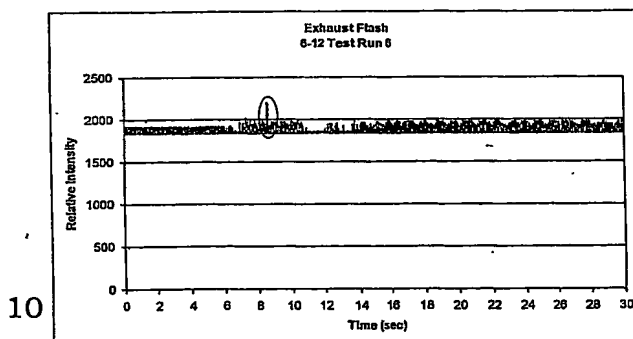

Exhaust flash was detected in test run 6 with nozzle 2 and nozzle 5 displaying moderate to severe fouling out of the six nozzles present during turbine

startup displayed at around 9 seconds into measurement circled on the graph. The

flash event was displayed in greater detail showing the response of the instant

invention to the short duration of the presence of flame in the initial stages of fouling

of the turbines six fuel nozzles with the flash clearly showing an impulse response

5 above the average intensity of the background radiation without the presence of

flash in the exhaust.
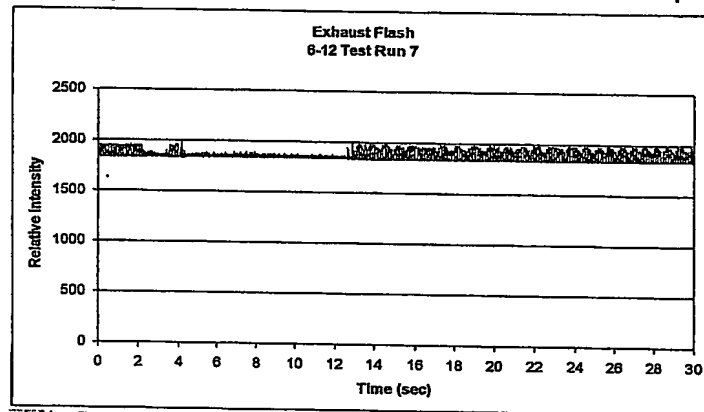
Subsequent test run 7 having similar nozzle condition failed to show any

flash present with similar conditions.

10
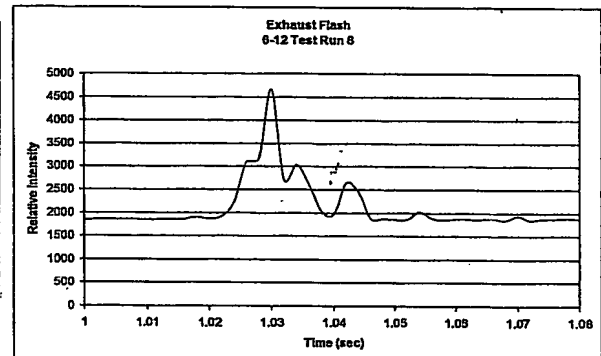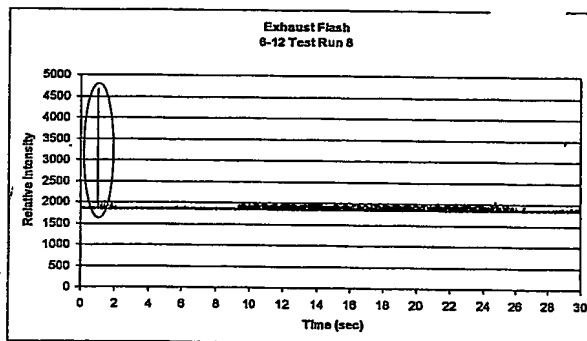
Test run 8 having nozzle 3 and 5 showing severe clogging and nozzles 2

and 6 showing partial clogging displayed a flash event of greater intensity. The

intensity of the flash being relatively proportional to the overall condition of the state

of the nozzles of the turbine.

Exhaust Flash
6-12 Test Run 9
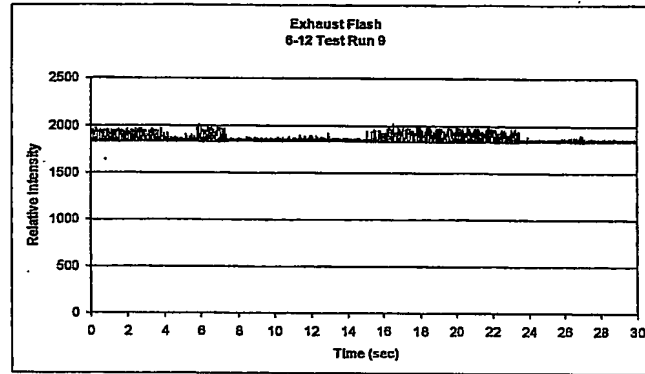
Test run 9 having similar nozzle condition to that of test 8 failed to

register a flash event even though evidence of visual flash was recorded during

testing. Individuals conducting the tests visually determined the presence of flash.

5 There was some confusion as to whether Test run 9 ever truly produced a visible

flash.

Exhaust Flash
6-12 Test Run 10

Exhaust Flash
6-12 Test Run 10
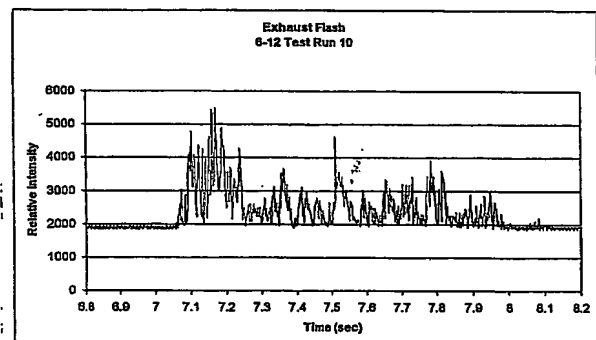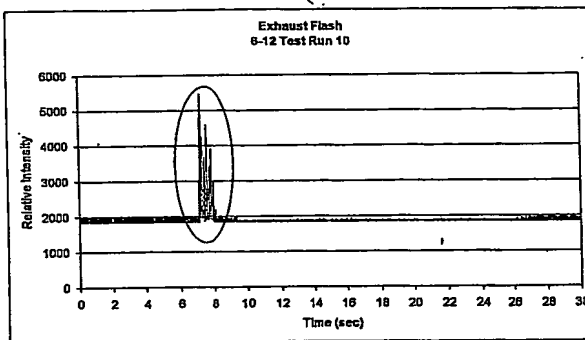
Test run 10 displayed above has 4 of the 6 fuel nozzles moderately to

severely fouled producing both a high intensity flash with a long duration.

Exhaust Flash
6-12 Test Run 11

Exhaust Flash
6-12 Test Run 11
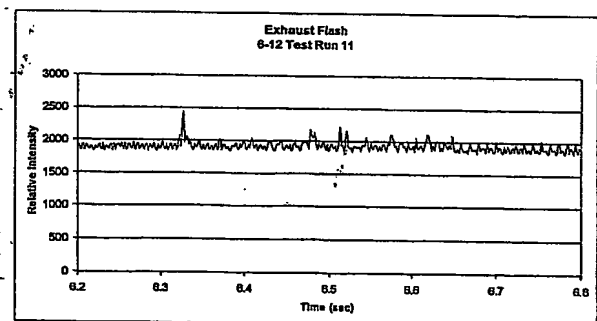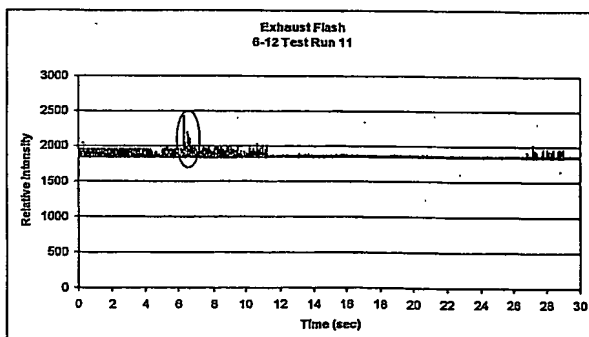
10

Test run 11 having similar nozzle condition to that of test run 10 has 4 of the

6 fuel nozzles moderately to severely fouled producing both a low intensity flash

with a relatively long duration.
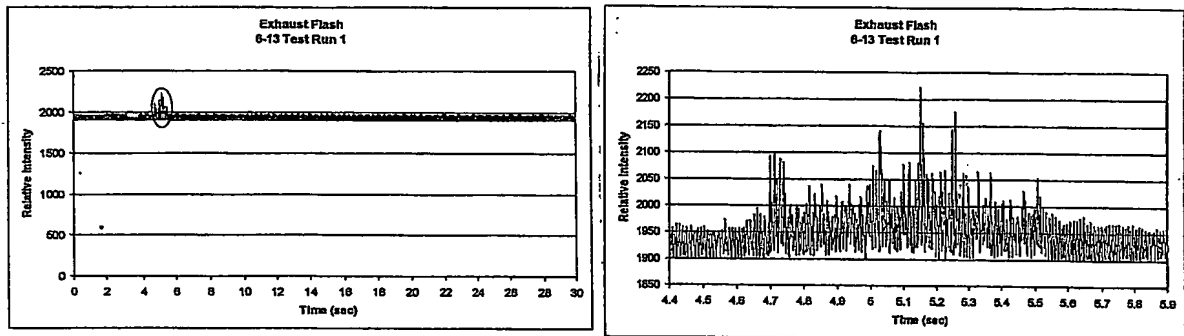
5   Test run 1, displayed above, conducted on the next day of testing had the

same nozzle condition to that of previous test run 11 having 4 of the 6 fuel nozzles

moderately to severely fouled producing both a low intensity flash with a long
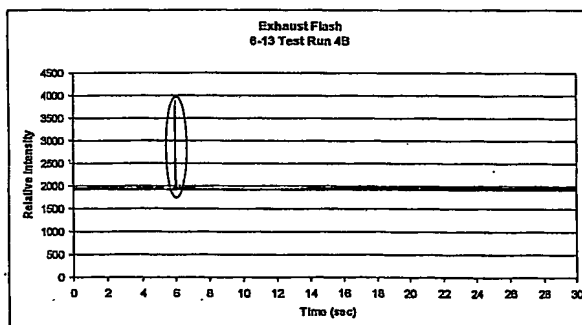
duration.
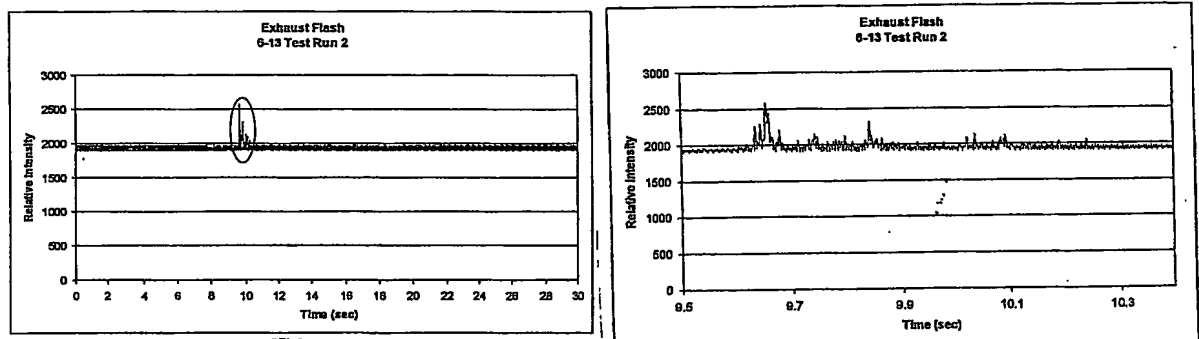
10   Test run 2, displayed above, conducted on the second day of testing had the

same nozzle conditions to that of previous test run 1 having 4 of the 6 fuel nozzles

moderately to severely fouled producing both a low intensity flash with a long
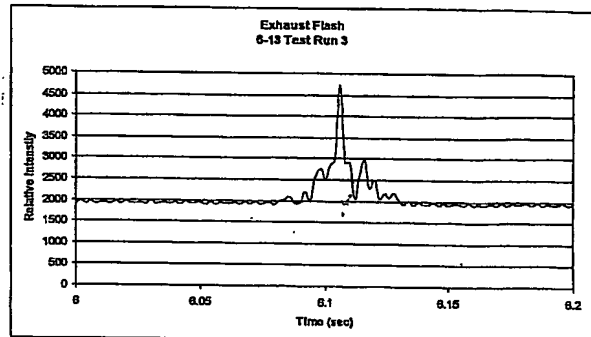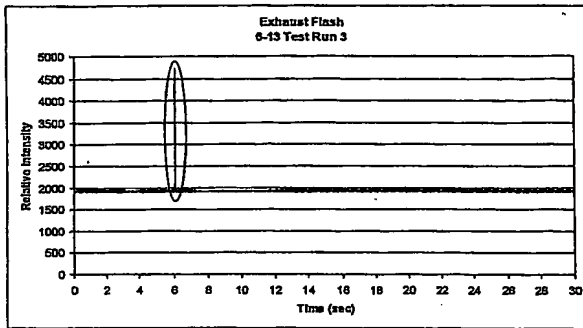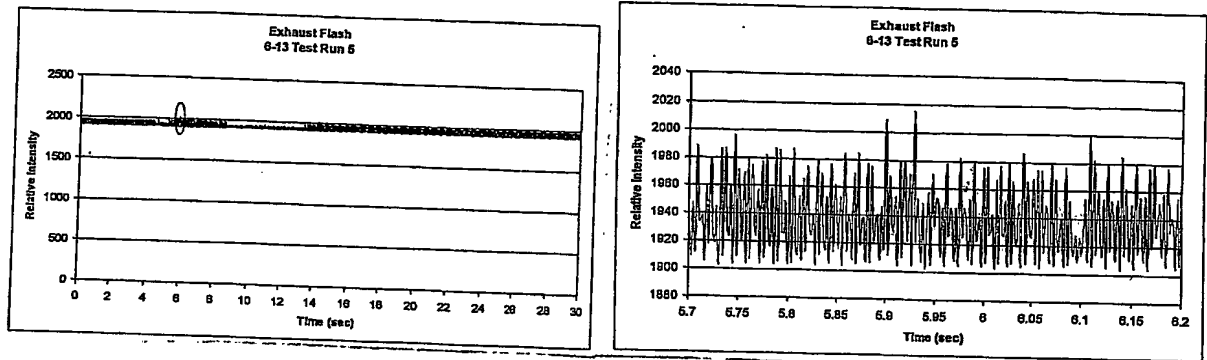
duration.

Test run 3, displayed above, conducted on the second day of testing had similar nozzle condition to that of previous test run 2 having 3 of the 6 fuel nozzles moderately to severely fouled producing both a high intensity flash with a short
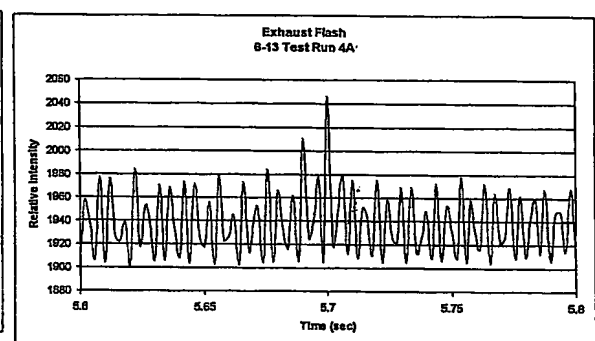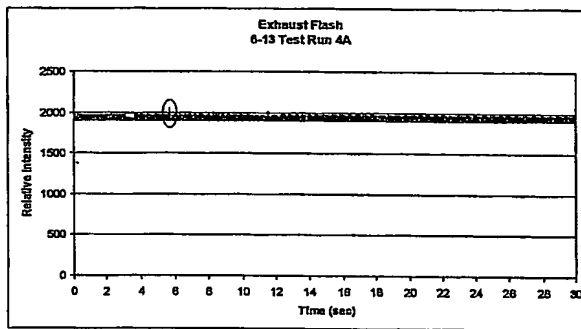
5   duration.

Test run 4A, displayed above, conducted on the second day of testing had 2 of the 6 fuel nozzles moderately fouled producing both a low intensity flash with a short duration that was detected by the optical sensor but not visually.

10
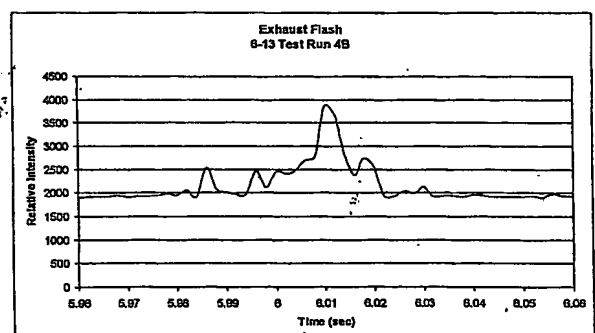
Test run 4B, displayed above, having nearly identical conditions to run 4A displayed a high intensity flash with a short duration.

Test run 5 displayed above displayed, having 4 of the 6 nozzles clean, with 2 partially fouled produced a low intensity flash of short duration.
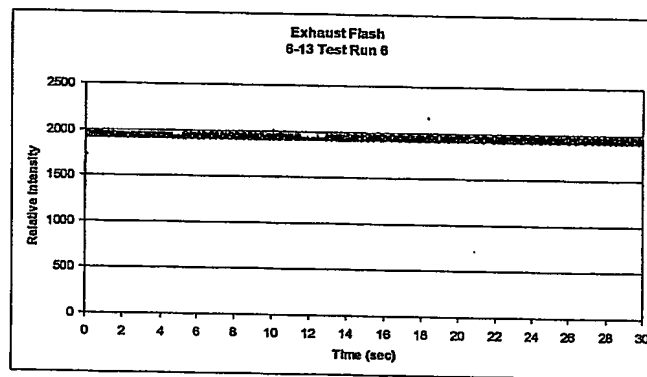
5   Test run 6, displayed above, had identical nozzle condition to test 5 and no flash was detected. The test data above is not intended to be the only potential embodiment and is only an initial test using one embodiment.

The testing data obtained from the Allison 501 turbine shows the correlation between the presence and duration of flame in the exhaust of a turbine and the

10   condition of the nozzles. Therefore analyzing the above preliminary data findings it is clear that with a single testing event of the startup of the gas turbine if the sensors detect a flame of high intensity (compared to the background radiation intensity) and/or a duration of a flame signature lasting for a period of at least 30 ms in duration it should indicate to the operator of the turbine that the majority of the

nozzles may be partially fouled and that it is an indicator that maintenance should be performed preferably before damage to the turbine occurs. The results displayed in test runs 6, 8 and 10-11 on the first test date and test runs 1-4B on the second test as displayed in the table above are preliminary findings and would need

5   to be correlated to costs to perform maintenance verses the probability of damage to the hot section of the turbine to determine if immediate maintenance of the turbine was necessary. This exact information when to cease operations to prevent permanent damage could be ascertained with more certainty after longer term evaluation of test data over a period of months or even years of a fleet of

10   turbines with proper flame presence monitoring. This long-term maintenance evaluation would not be possible without the data acquired from the flame sensor(s).

The testing for normal service should ideally be performed from the first start of the turbine after entry into service when the fuel nozzles are known to be in a

15   clean condition. This initial data can be set as a baseline for storage in the E.O.M. to indicate the ideal condition of the turbine. Subsequent data from continued operation of the turbine can then be compared to the initial baseline to produce a trend line to indicate to the operator the anticipated time for service for the individual turbine assuming a linear progression of clogging and if an unexpected change in

20   the condition of the fuel nozzle occurs as discussed above an alarm or indication to the operator that immediate service is needed to prevent damage to the hot sections of the turbine.

The following is an explanation for the graph of FIG. 9, which describes the

methodology for determining the nature of a flash event: The threshold reference

level **60** is a smoothing function of the sample intensity **62**. It will be used to

establish the trip point **64** for starting to integrate the flash interval **76**. Once the

5   relative intensity **66** reaches the trip point level **68**, the reference threshold **62** is

frozen and the starting point **63** is signaled. Then the relative intensity **66** is

integrated and the time duration **76** along with the maximum peak **72** is tracked

until the relative intensity **66** goes below the trip point level **74**. This will signal the

ending point **78** at which time the threshold reference **60** will be released to be

10   readied for the next flash interval **80**.

The specific equations below are preferably used and are optionally

preformed by a microprocessor are as follows:

Used for establishing the threshold level.

15

Where α = running average interval

n = discrete sample number

NT = noise threshold

$$T_i = \frac{1}{\alpha} \sum_{n=i+1}^{\alpha+i} \sqrt{X_n^2} + NT \Big|_{i=0}^{\infty}$$

20   Used for retrieving the sample intensity value.

Where α = running average interval

n = discrete sample number

●   ●

$$SI_i = \frac{1}{\alpha} \sum_{n=i+1}^{\alpha+i} \sqrt{X_n^2} \Bigg|_{i=0}^{\infty}$$

Used to establish the beginning point of the flash interval. At this point in time the threshold level would be frozen until the sample intensity value gets below the threshold level.

5

$$B = SI_i > T_i \Bigg|_{i=0}^{\infty}$$

Used to establish the ending point of the flash interval.

10

$$E = SI_i < T_{frozen} \Bigg|_{i=0}^{\infty}$$

Used to establish the total integrated intensity value.

$$I = \sum_{B}^{E} SI_i - T_{frozen} \Bigg|_{i=0}^{\infty}$$

15   Used to establish the total time captured for the flash interval

$$C = \sum_{B}^{E} i \Bigg|_{i=0}^{\infty}$$

Used to establish the peak intensity value.

$$P = SI_i \max \Big|_{i=0}^{\infty}$$

It will be appreciated that the examples provided in the instant specification

5   and claims are set forth by way of illustration and do not depart from the spirit and

scope of the instant invention. It is to be understood that the instant invention is by

no means limited to the particular embodiments herein disclosed but is much

broader, it also comprises any modifications or equivalents within the scope of the

claims.

10   Having thus described my invention, what I claim as new and desire to

secure by United States Letters Patent is:

We Claim:

1. An apparatus for detecting the presence of flame in the exhaust path of a gas turbine engine comprising:

an optical viewing port capable of being mounted to the gas turbine engine exhaust section to collect the radiant energy present in the exhaust path;

a sensor element that is sensitive to the radiant energy produced from flame transmitted from said optical viewing port, wherein said sensor element emits an electrical signal when radiant energy is present; and,

an output means connected to said sensor element activated when flame has been detected in the exhaust path of the gas turbine causing the electrical signal.

2. The apparatus for detecting the presence of flame in the exhaust path of a gas turbine engine of claim 1 further comprising:

a fiber optic cable assembly mounted to receive the radiant energy from said optical viewing port;

an electro-optics module that restricts the spectral energy to wavelengths specific to the signatures of the flame source from a wavelength of 200 nm to 800 nm.

3. The apparatus for detecting the presence of flame in the exhaust path of a gas turbine engine of claim 1 further comprising:

a computer to receive said output and make a determination of the state of

the fuel nozzle clog.

4. The apparatus for detecting the presence of flame in the exhaust path of a gas

turbine engine of claim 1 further comprising:

a storage device capable of saving said electrical signal from said sensor

element for later analysis.

5. The apparatus for detecting the presence of flame in the exhaust path of a gas

turbine engine of claim 1 further comprising:

a fiber optic cable assembly mounted to receive the radiant energy from

said optical viewing port;

a collection optics to receive the radiant energy from said fiber optic cable

and efficiently couple the radiant energy to said sensor element.

6. An apparatus for determining the condition of the fuel nozzle of a gas turbine

comprising:

an optical viewing port capable of being mounted to the gas turbine engine

to collect the radiant energy from the exhaust path;

a fiber optic cable assembly mounted to receive the radiant energy from

said optical viewing port;

an electro-optics module configured to receive the radiant energy from the

fiber optic cable and indicate when flame has been detected in the exhaust path

of the gas turbine.

7. A method of determining the state of the fuel nozzle of a gas turbine

comprising the steps of:

receiving radiant energy from the exhaust path of a gas turbine;

transferring the radiant energy to at least one sensor capable of detecting

radiant energy; and,

indicating when radiant energy within the range has been received from

the exhaust path.

8. The method of determining the state of the fuel nozzle of a gas turbine of

claim 7 further comprising the steps of:

amplifying the radiant energy from the exhaust path of the gas turbine.

9. The method of determining the state of the fuel nozzle of a gas turbine of claim

7 further comprising the steps of:

filtering the radiant energy to a wavelength of about 200 to 800 nm.

10. A method of determining the state of the fuel nozzle of a gas turbine

comprising the steps of:

receiving radiant energy from the exhaust path of a gas turbine;

transferring the radiant energy to at least one sensor capable detecting

radiant energy produced from a flame presence in the exhaust;

determining the average of the baseline of the normal background intensity

of the radiant energy of a gas turbine known to be operating efficiently with clean

fuel nozzles;

producing a signal from at least one of the sensors when the radiant

energy in the 200 nm to 800 nm range has been received from the exhaust path;

comparing the output of the sensor to the known baseline;

signaling the presence of flame when the signal produced has a relative

intensity greater than that of the average baseline intensity.

11. The method of determining the state of the fuel nozzle of a gas turbine of

claim 10 further comprising the steps of:

storing the baseline and signal produced from a sensor that indicated the

presence of a flame in the exhaust.

12. The method of determining the state of the fuel nozzle of a gas turbine of

claim 10 further comprising the steps of:

measuring the duration of time that the relative intensity of the signal

produced is greater than the baseline;

indicating to the operator of the gas turbine if the duration of time exceeds

30 ms.

13. The method of determining the state of the fuel nozzle of a gas turbine of

claim 10 further comprising the steps of:

measuring the intensity of the signal produced from the sensor;

indicating to the operator of the gas turbine if the sensor output reaches a

level greater than the average relative intensity of the baseline by a

predetermined amount based on the level of turbine activity.

14. A method of detecting the presence of flame in the exhaust of a turbine

comprising the steps of:

gathering a light energy by the view port attached to the exhaust plenum;

transmitting said light energy by a fiber optic cable into a spectrometer

through a fixed aperture;

striking light energy against a collimating mirror;

directing said light energy at a diffraction grating;

refracting light by a grating;

directing toward a focusing mirror;

reflecting diffracted light to strike onto a focusing mirror;

focusing onto a detector array;

.concentrating light In front of the detector array with a lens onto an

individual detectors;

responding to the individual wavelength of light that strikes a detector

element (pixel) with an electrical signal;

feeding said signals into a microprocessor;

interpreting a signal strength and information relative to the intensity of the

individual wavelengths of light as received by said detector array and,

providing information to end user of the gas turbine.

15. The method of claim 14 further comprising the steps of:

limiting the effects of second and third order wavelength harmonics using

an order sorting filter.

16. The method of claim 14 further comprising the steps of:

determining the spectral nature of the flame condition being monitored.

17. The method of determining presence of flame in the exhaust of a gas turbine

comprising the steps of:

collecting spectral energy from the exhaust portion of a gas turbine;

transmitting said spectral energy to a spectrometer optics comprising a

chopper, at least one prism that serves as a disperser, and parabolic optical-path-

folding mirrors;

projecting spectrally dispersed light onto an array of photodetectors;

controlling the chopper, synchronizing readout from the pixels with the

chopping cycle, and sending data to an external computer or data logger with

electronic circuitry, at the repetition frequency of at least 390 Hz.

18. The method of claim 17 wherein said photodetector is lead selenide based.

19. The method of determining presence of flame in the exhaust of a gas turbine

comprising the steps of:

  collecting spectral energy from the exhaust portion of a gas turbine;

  transmitting said spectral energy to a sensor;

  producing an electrical signal corresponding to the intensity and presence

of a flame in the exhaust;

  storing the electrical signal in a storage device.

20. The method of determining presence of flame in the exhaust of a gas turbine

of claim 19 further comprising the steps of:

  providing a computer processor to evaluate the electrical signal.

21. The method of determining presence of flame in the exhaust of a gas turbine

of claim 20 further comprising the steps of:

  performing with the computer processor operations comprising:

   establishing a threshold level

$$T_l = \frac{1}{\alpha} \sum_{n=l+1}^{\alpha+l} \sqrt{X_n^2} + NT \Bigg|_{i=0}^{\infty}$$

    wherein α = running average interval, n = discrete

  sample number, NT = noise threshold;

  determining a sample intensity value

$$SI_i = \frac{1}{\alpha} \sum_{n=i+1}^{\alpha+i} \sqrt{X_n^2} \bigg|_{i=0}^{\infty}$$

wherein α = running average interval, n = discrete sample number;

freezing the threshold level until the sample intensity value gets below the threshold level;

establishing an ending point of the flash interval

$$B = SI_i > T_i \bigg|_{i=0}^{\infty};$$

establishing a total integrated intensity value

$$E = SI_i < T_{frozen} \bigg|_{i=0}^{\infty};$$

establishing a total time captured for the flash interval

$$I = \sum_B^E SI_i - T_{frozen} \bigg|_{i=0}^{\infty}$$

$$C = \sum_B^E i \bigg|_{i=0}^{\infty};$$

establishing a peak intensity value

$$P = SI_i \max \bigg|_{i=0}^{\infty};$$

wherein the results of operations T_1, SI_1, B, E, I, C and P produced are stored in a memory device.

22. The method of determining presence of flame in the exhaust of a gas turbine

of claim 21 further comprising the steps of:

comparing the stored results of operations T_1 , SI_1 , B, E, I, C and P;

determining that a condition requiring maintenance of the nozzles exists.

23. The method of determining presence of flame in the exhaust of a gas turbine

of claim 22 further comprising the steps of:

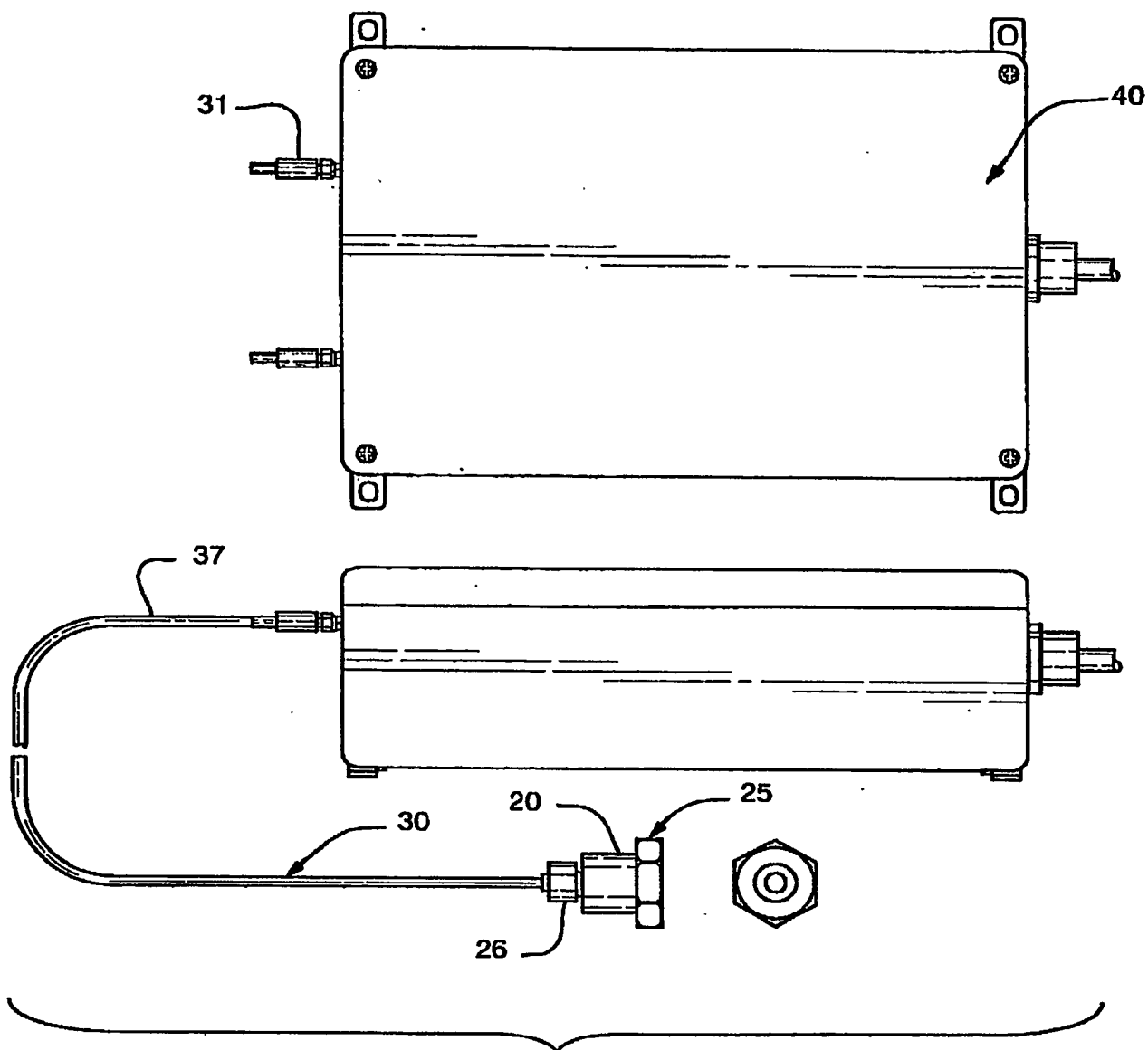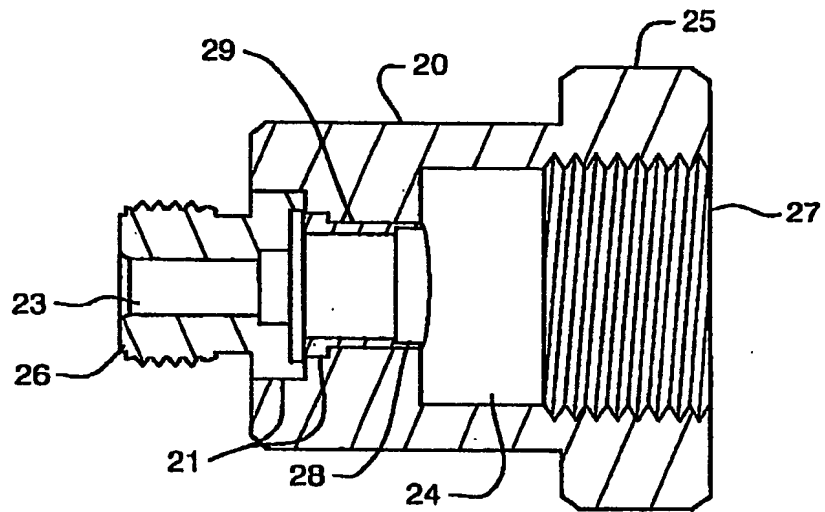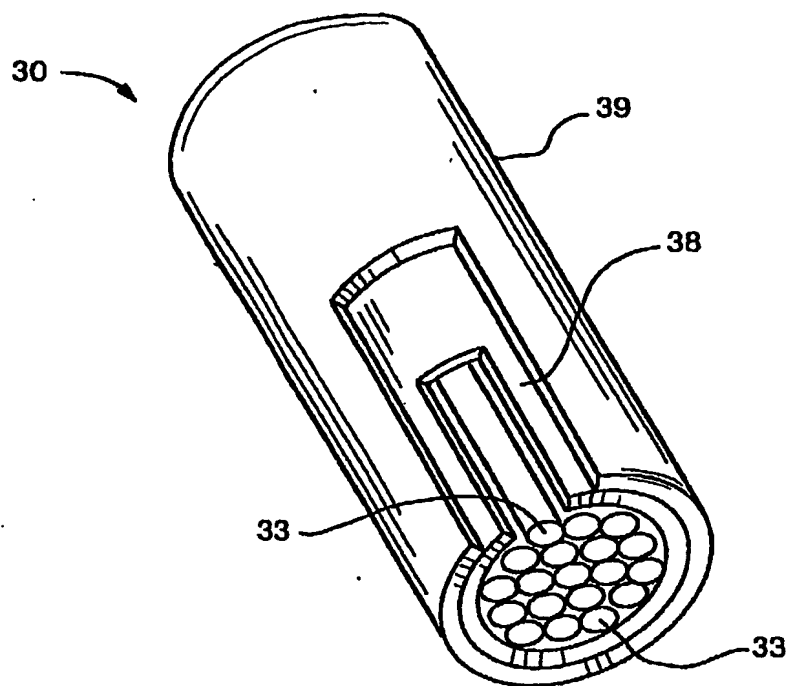indicating that a condition requiring maintenance of the turbine exists.
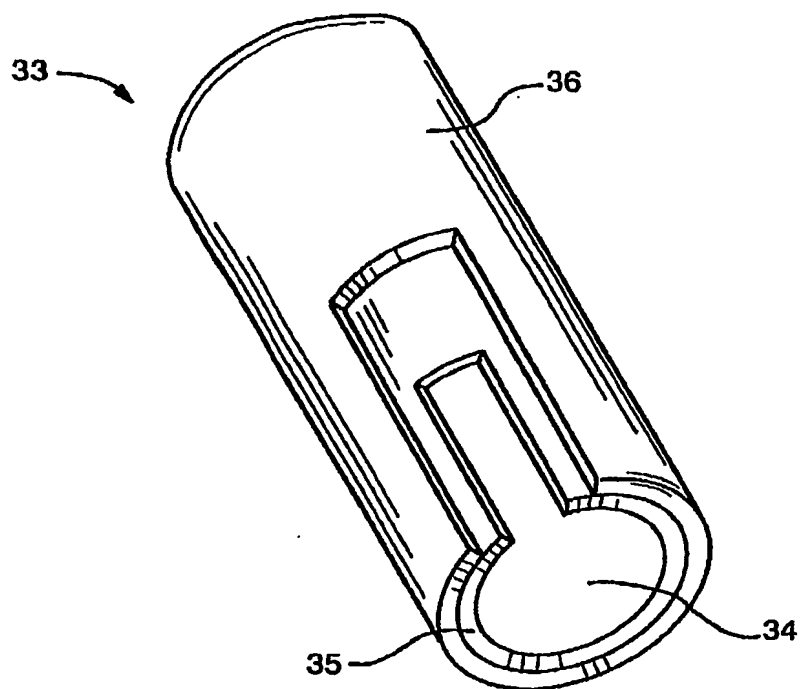
FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

$S_{rel} = f(\lambda)$
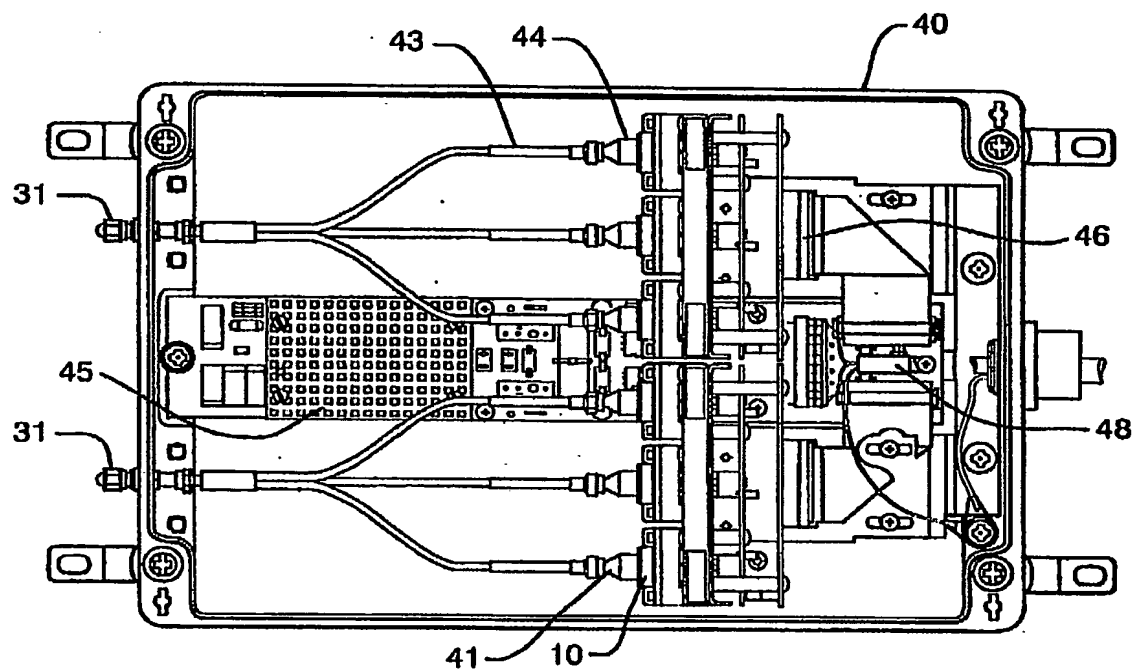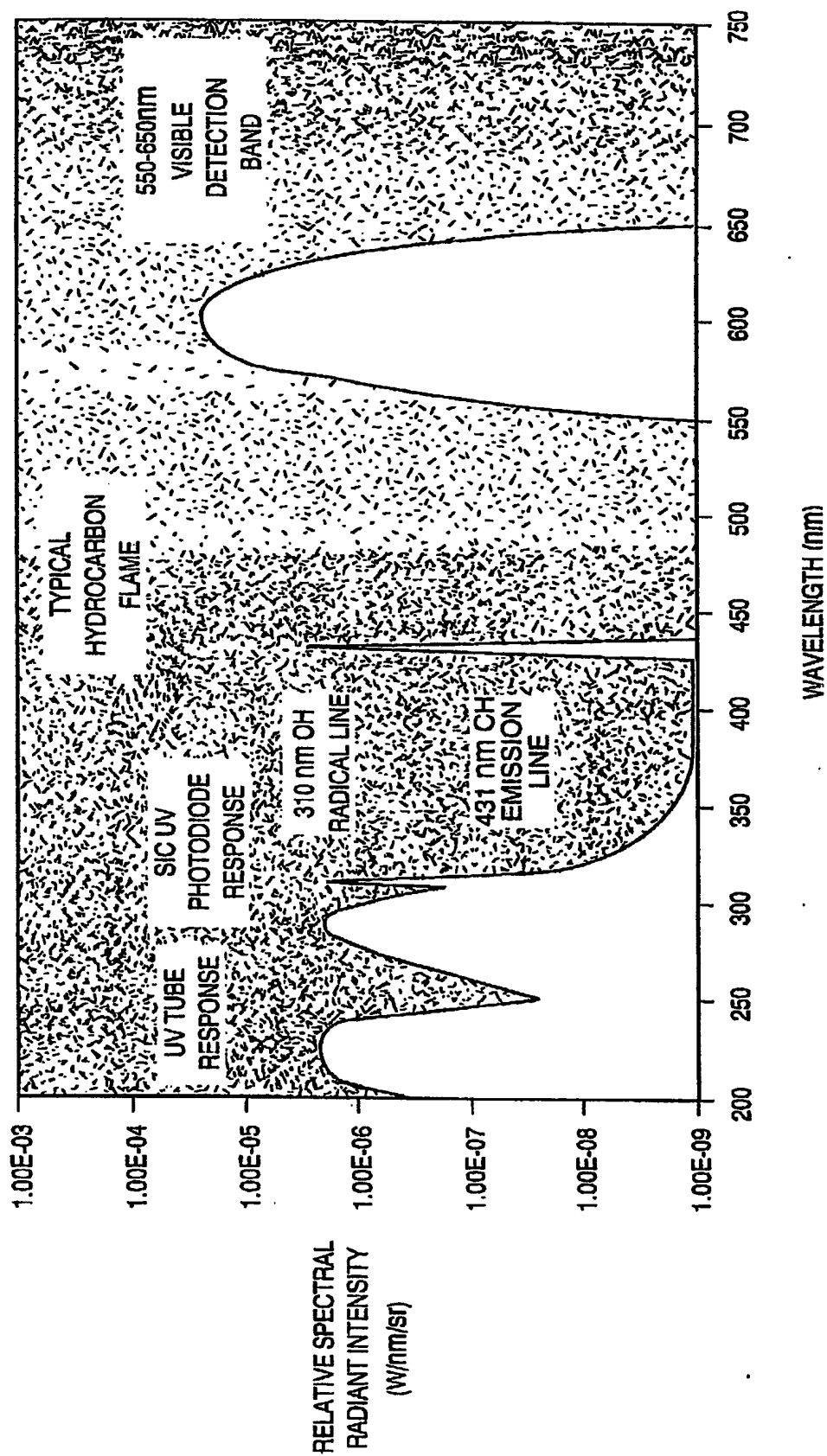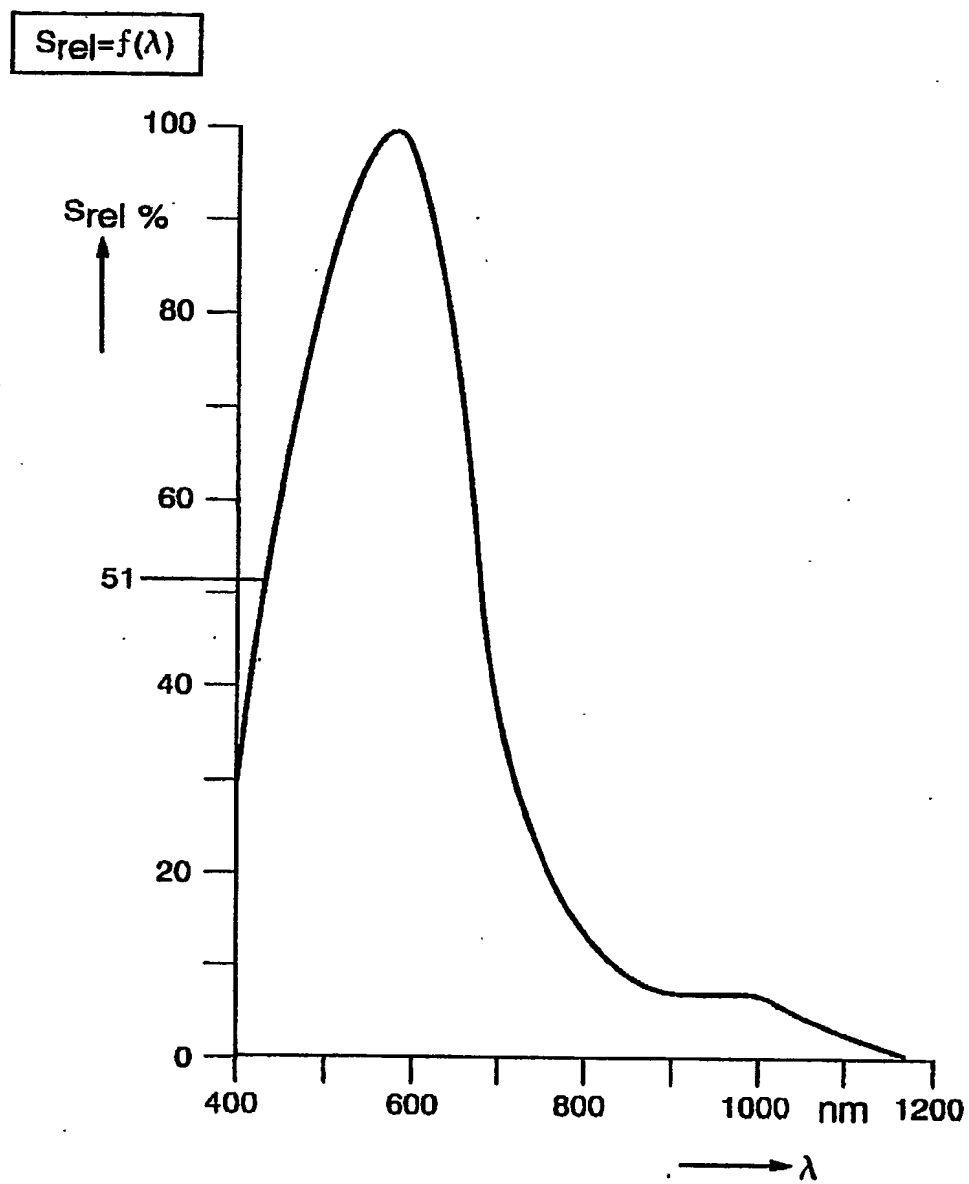

FIG. 7
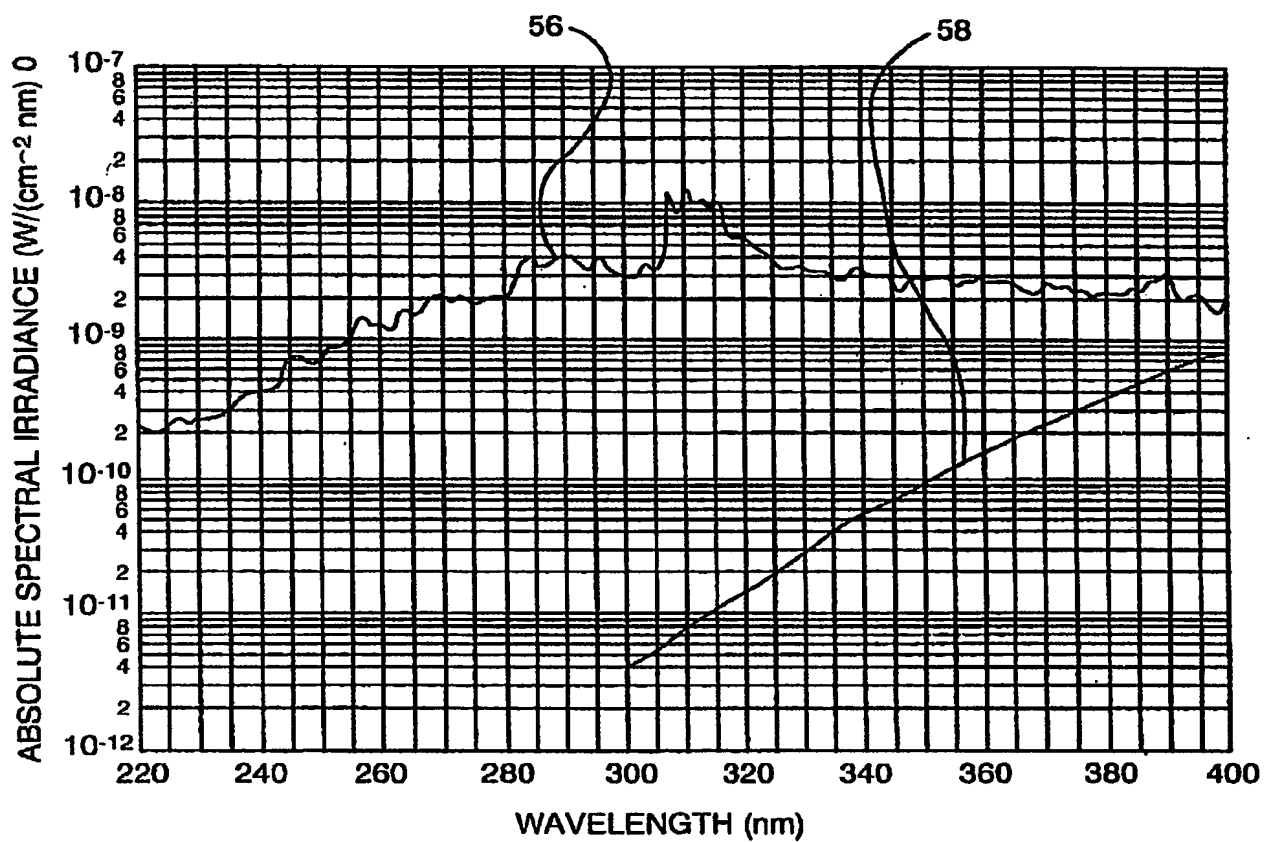
FIG. 8
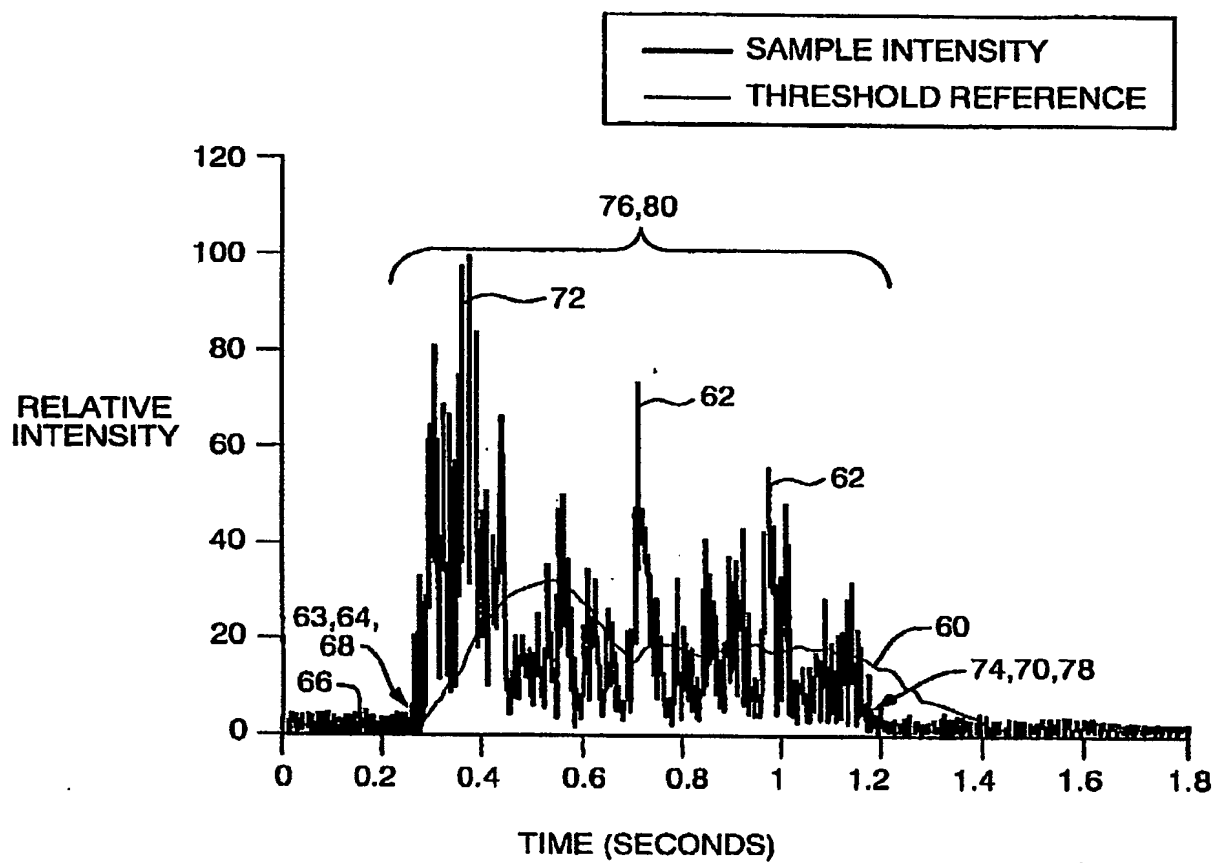
FIG. 9

NOZZLE	FLOW RATE LB/HR	SPRAY ANGLE (DEG.)	REMARKS	CONDITION
IDEAL	28-31	78-88		CLEAN
A	31	77		PARTIAL
B	31	81		CLEAN
C	31	77	GOOD FLOW	PARTIAL
D	-	-	BAD THREADS	UNKNOWN
E	31	87	GOOD	CLEAN
F	0	0	PILOT CLOGGED	FULL

FIG. 10

TEST RUN	NOZZLE CONDITION (DEGREE OF CLOGGING)						COMBINED SEVERITY	FLAME OBSERVATION
	NOZZLE 1	NOZZLE 2	NOZZLE 3	NOZZLE 4	NOZZLE 5	NOZZLE 6		
2	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	1	NONE
3	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	1	NONE
4	CLEAN	CLEAN	PARTIAL	CLEAN	CLEAN	PARTIAL	2	SMALL
5	CLEAN	CLEAN	PARTIAL	CLEAN	CLEAN	PARTIAL	2	NONE
6	CLEAN	UNKNOWN	PARTIAL	CLEAN	PARTIAL	PARTIAL	3	NONE
7	CLEAN	UNKNOWN	PARTIAL	CLEAN	PARTIAL	PARTIAL	3	NONE
8	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	PARTIAL	2	SMALL
9	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	PARTIAL	2	SMALL
10	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	FULL	4	LARGE
11	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	FULL	4	SMALL
12	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	FULL	4	LARGE
13	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	FULL	4	MEDIUM
14	CLEAN	UNKNOWN	CLEAN	CLEAN	PARTIAL	PARTIAL	2	MEDIUM
15	CLEAN	UNKNOWN	PARTIAL	CLEAN	PARTIAL	PARTIAL	3	MEDIUM
16	CLEAN	CLEAN	PARTIAL	CLEAN	CLEAN	PARTIAL	2	NONE
17	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	CLEAN	1	NONE

FIG. 11

FIG. 12